

SPECIFICATION AMENDMENTS:

Please replace the specification with the enclosed substitute specification. A marked-up version of the substitute specification showing the changes made relative to the previous version of the specification is also attached to this amendment. Thus, both a clean version and a marked up version of the specification are being submitted herewith as per 37 C.F.R. §1.125. No new matter has been added.

**IMPROVED METHOD AND APPARATUS FOR TRACKING A RESONANT
FREQUENCY**

5 FIELD OF THE INVENTION

The present invention relates to improved methods for tracking resonant frequencies of electrically resonant structures, in particular structures, which are mounted remotely from the driving and sensing electronics.

10 BACKGROUND OF THE INVENTION

International patent application no. WO 98/21818 discloses a system for tracking the resonant frequency of an electrically resonant structure in which a variable frequency oscillator, which generates an excitation signal of a variable frequency encompassing the possible resonant frequency range of the target resonant structure, is connected to the resonant structure by a bi-
15 directional RF transmission line. The proportion of the excitation signal energy reflected and the proportion dissipated by the resonant structure will depend upon the difference between the frequency of the excitation signal and the resonant frequency of the resonant structure, and the transmission line incorporates a directional coupler, which generates a directional coupler signal proportional to the reflected signal from the resonant structure. The directional coupler signal is
20 conditioned by a processor to provide a feedback signal to the input of the variable frequency oscillator such that the mean frequency of the excitation signal is caused continuously to track the varying resonant frequency of the resonant structure.

This arrangement has particular application in the non-contact torque measurement using SAW
25 (surface acoustic wave) devices as the sensing elements. Many such applications, however, use two SAW devices attached to a rotating shaft in such a way that when torque is applied one resonator is put in tension whilst the second is put in compression. This causes the resonant frequency of the first device to reduce whilst the second will increase. The two devices would normally have a nominal difference between them of 1 MHz, such that with torque the output
30 from the system is a difference frequency that changes about 1 MHz with applied torque. However, in order to be used in conjunction with the tracking system of the prior art, the two sensors on the shaft must be electrically connected to the stator of the assembly via two pairs of

non-contacting rotary coupled transmission lines. The use of two pairs of couplers has the disadvantage that the size and complexity of the mechanical assembly is increased, and thereby the cost. In addition, the rotary coupled transmission line can load the SAW resonator and thereby modify its frequency. As the system is a differential one, if both couples modify their
5 respective sensor response by the same amount, then this effect can be cancelled out, but if the two channels are not identical then an error in the reading obtained can result.

The arrangement of the prior art has the further disadvantage that the requirement for a directional coupler increases the complexity of the arrangement.

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SUMMARY

According to one aspect of the present invention there is provided a method of tracking the resonant frequency of an electrically resonant structure comprising the steps of exciting the resonant structure with a reference signal of a variable frequency encompassing the possible
15 resonant frequency of the resonant structure, mixing a response signal from the resonant structure with the reference signal, filtering the mixed response and reference signals to remove the sum products from the composite signal, and using the resulting amplitude modulation component of the response signal within a control loop to track the resonant frequency of the resonant structure.

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The present invention further provides an apparatus for tracking the resonant frequency of an electrically resonant structure, comprising a variable frequency oscillator providing an excitation signal of a variable frequency encompassing the possible resonant frequency of said resonant structure, coupling means connecting said variable frequency oscillator to said resonant
25 structure, an I-mixer forming a synchronous detector having a first input connected to said oscillator and a second input connected to the coupling device, the I-mixer mixing the excitation signal from the variable frequency oscillator with a response signal generated by the resonant structure in response to the excitation signal, a filter connected to the output of the I-mixer which filters the output of the I-mixer to remove the sum products of excitation and response signals,
30 thereby leaving just an amplitude modulation component of the signal, and processing means which processes the filtered signal to track the resonant frequency of the resonant structure.

An apparatus for and method of tracking a resonant frequency in accordance with the invention has the advantage that it enables multiple resonant structures to be connected together and interrogated through a single channel, whilst, at the same time, obviating the need for a directional coupler to be used.

Preferably, the reference signal from the oscillator is mixed, through the coupling means, with a second reference signal from a second oscillator of a variable frequency encompassing the possible resonant frequency of a second resonant structure, the first and second resonant structures having a nominal difference frequency, and said first and second resonant structures are excited with said mixed signal. The composite response signal of said first and second resonant structures is then mixed with the first reference signal, the mixed signal filtered using a filter, preferably a low pass filter, and the resulting signal used within a control loop to track the resonant frequency of the first resonant structure, and it is also mixed with the second reference signal, by a separate mixer, the mixed signal filtered and the resulting signal used within a control loop to track the resonant frequency of the second resonant structure. In this way, it is possible to track the resonant frequency of a pair of structures connected in parallel through a single channel. The coupling of the two signals to the resonant structures is preferably achieved by use of a summer connected to the input of the coupling means.

An impedance such as a resistor is preferably provided between the oscillator and the resonant structure, in particular between the oscillator and the coupling means. Furthermore, the or each signal source preferably has a low output impedance, which has the advantage of suppressing any amplitude modulation of the or each reference signal.

In a particularly preferred embodiment of the invention, a Q-mixer is provided for the or each signal source, to one input of which is connected the signal source through a phase shifter which shifts the reference signal received at the first input by preferably 90 degrees, and to the other input of which is connected the coupling means so as to deliver the response signal thereto. The output of the or each Q-mixer is similarly filtered to remove the sum products of the input signals, thereby leaving just the amplitude modulation component of the response signal. The

square of that signal is then summed with the square of the filtered signal output of the associated I-mixer and then processed to track the resonant frequency of the associated resonant structure. In this way, errors in the tracked frequency resulting from the phase delay of the signal at the input of the coupling device are eliminated.

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The squaring and summing operations may be carried out digitally by use of A/D converters and suitable digital processing means, which may also calculate first harmonic amplitudes of the demodulated signals produce codes for controlling the carrier frequency of the signal sources. Alternatively, analog signal squaring means may be utilized, such as a mixer with its inputs linked.

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It will, of course, be understood that the system may be expanded to track the resonant frequencies of more than two structures, such as SAW devices. For such multiple resonant structures, there is preferably a nominal frequency difference between each device of at least 1 MHz.

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BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be well understood, there will now be described some embodiments thereof; given by way of example, reference being made to the accompanying drawings, in which:

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Figure 1 is a simplified schematic representation of a system embodying the invention suitable for tracking the resonant frequency of a single structure;

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Figure 2 is a schematic representation of a system embodying the invention suitable for tracking the resonant frequency of two resonant structures; and

Figure 3 is a schematic representation of a system according to an alternative embodiment containing two resonant structures with I and Q synchronous detectors.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring first to Figure 1, there is shown a simplified schematic of a system embodying the invention. The output of a signal source 3 is connected directly to one input 5a of a mixer 5 and through a resistor 4 to the input of a coupling device 2, which, in turn, is connected to a single SAW resonator 1. The input of the coupling device 2 is also connected to a second input 5b of the mixer 5. The coupling device preferably takes the form of a rotational contactless coupler, but other coupling devices are also possible, and the signal source 3 takes the form of a high frequency oscillator with a center frequency within the bandwidth of the resonator 1 and it is frequency modulated again within a deviation that is within the bandwidth of the resonator.

Upon operation of the system, the SAW resonator 1 is excited by the reference signal from the signal source 3. The impedance of the SAW resonator 1 will change rapidly with frequency around its resonant point and will form a potential divider with the resistor 4, so that when the impedance of the resonator 1 is high compared with that of the resistor 4, there will be minimal voltage drop across the resistor 4, whereas when the impedance of the resonator 1 is low compared with that of the resistor 4, there will be a large voltage drop across the resistor 4 and minimal across the resonator 1. In this way, the amplitude of the response of the SAW 1 to the reference signal, as seen at the second input 5b of the mixer 5 from the coupling device 2, will also vary as the frequency of the signal source 3 is modulated. By using a signal source 3 of low output impedance, the amplitude modulation of the output of the signal source 3 fed to the first input 5a of the mixer will be suppressed. As a result, the mixer 5, acting as a synchronous detector, will output through its output line 5c a signal which will be the sum of the driving signal from the signal source 3 and the amplitude modulated signal response of the resonator 1. A low pass filter 6 is then used to remove the sum products of the signals, leaving just the amplitude modulation component of the signal which can then be used within a control loop to track the resonant frequency of the SAW device 1 in the manner described in W098/21818.

In a development of this embodiment not illustrated, a buffer is inserted in front of the resistor 4 that further reduces the parasitic amplitude modulation in the reference signal.

Figure 2 shows a schematic representation of how the system of Figure 1 can be used to connect

together and interrogate two SAW resonators which have a nominal difference frequency of; say, 1Mhz through a single channel which requires just a single coupling device. The two SAW devices 11, 21 are arranged in parallel and connected to the coupling device 2 which is, in turn, connected to the output of a summer 20. One input of the summer 20 is connected to one input 15b of a first mixer 15 and through a first resistor 14 to a first signal source 13, which generates a first reference signal, the first signal source also being coupled directly to the other input 15a of the first mixer 15. The other input of the summer 20 is connected to one input 25b of a second mixer 25 and through a second resistor 24 to a second signal source 23, which generates a second reference signal, the second signal source also being coupled directly to the other input 25a of the second mixer 25. Each of the signal sources 13, 23 takes the form of a high frequency oscillator with a center frequency within the bandwidth of its associated resonator 11, 21 and it is frequency modulated again within a deviation that is within the bandwidth of its associated resonator 11, 21. The coupling device 2 again preferably takes the form of a rotational contactless coupler, but other coupling devices are also possible.

Each half of the system then operates in the same manner as described above in relation to Figure 1, with the reference signal from the first signal source 13 exciting the first SAW 11 and the reference signal from the second signal source 23 exciting the second SAW 21. The amplitude modulated response signals from the two SAWs 11, 21 will then be fed back through the coupling device 2 and the combined signals fed to the inputs 15b, 25b of both the first and the second mixer 15, 25 by the summer 20. At the first mixer 15, the combined response signal is mixed with the reference signal from the first signal source 13 and the sum products are then removed by the first low pass filter 16 connected to the output 15c of the first mixer 15. Furthermore, because of the nominal difference frequency between the two SAWs and because the amplitude modulation caused by each SAW device 11, 21 will be at the same fundamental and harmonic frequencies, the output of the first low pass filter 16 can easily be processed electronically in a manner well known to the skilled person to separate out the amplitude modulated component of the response from the first SAW 11. This can then be used within a control loop to the first signal source 13 to track the resonant frequency of the first SAW 11.

Similarly, at the second mixer 25, the combined response signal is mixed with the reference

signal from the second signal source 23 and the sum products are then removed by a second low pass filter 26 connected to the output 25c of the second mixer 25. The output of the second low pass filter 26 can then be processed electronically to separate out the amplitude modulated component of the response from the second SAW 21 due in the nominal frequency difference between the first and second SAWs 11, 21. This can then be used within a control loop to the second signal source 23 to track the resonant frequency of the second SAW 21.

For example, if the SAW devices 11, 21 have nominal frequencies of 200MHz and 201 MHz, giving a nominal difference frequency of 1 MHz and the amplitude modulation caused by each SAW device is at 5kHz with the 2nd harmonics at 10kHz, these will be excited by the reference signals produced by the two signal sources 13, 23 having frequencies of 200MHz FM and 201 MHz FM respectively. When the 200MHz FM signal is mixed with the composite 200 and 201 MHz FM response signal with amplitude modulation from the SAWs 11, 21, the difference product will be the 5kHz signal generated by the modulation due to the excitation of the 200MHz SAW, the modulation caused by the 201 MHz device being offset by 1MHz and therefore easily filtered out. Similarly, when the 201 MHz FM signal is mixed with the composite response signal, the modulation caused by the 200 MHz SAW can also easily be filtered out.

A drawback with the embodiments described above in relation to Figures 1 and 2 is that the actual frequencies that will be tracked using the demodulated signal produced by the synchronous detector will slightly differ from the resonant frequency of the SAW device and the amount of this difference will depend on the phase delay of the signal at the input of the coupling device. In some cases it may be difficult to ensure a high stability of the phase delay, which will result in random errors in the measurement of the resonant frequency. Figure 3 shows a third embodiment of the invention in which phase delay effects are eliminated by mixing the reference and response signals for each signal source in an IQ mixer and producing the demodulated signal as a sum of the squares of the signals at I (in-phase) and Q (Quadrature) outputs of the IQ mixers 30, 40. This is achieved by supplementing the system of figure 2 with an additional pair of Q-mixers 32, 42, one associated with each signal source 13, 23.

One input of the first Q-mixer 32 associated with the first signal source 13 is connected to the

first signal source 13 through a 90 degree phase shifter 31 so as to receive a phase shifted version of the reference signal from the first signal source 13. The other input of the first Q-mixer 32 is connected to the summer 20 so as to receive the response signals from the two SAW devices 11, 21. The output of the first Q-mixer 32 is then filtered using a low pass filter 33 before being squared and then summed with the filtered and squared output of the first mixer 15, which is based in the in-phase reference signal. The sum of the squares of these two signals will not, then, depend on the phase delay of the input signal.

The squaring and summing of the signals may be achieved by analog means using looped mixers 34, 35 and a summer as shown in Figure 3. Alternatively, the output of the low pass filters 16, 33 can be converted into digital signals using A/D converters and the squaring and adding of the signals performed by a digital processor. Apart from performing the squaring and adding functions, the digital processor will also calculate the first harmonic amplitudes of the demodulated signals and produce the codes that will control the carrier frequencies of the digital synthesizers used as the signal sources.

It will, of course, be understood that a second Q-mixer 42, phase shifter 41 and low pass filter 43 will be associated with the second signal source 23.